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Environmental Monitoring Report
10 MW Gas Suspension Absorption Demonstration Project

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TEST SUMMARY

The "10-MW Gas Suspension Absorption (GSA) Demonstration" project, executed over a period of three years has recently been completed. The eighteen-month test program was hosted at TVA's Center for Emissions Research (CER). All three of the major objectives of the demonstration were successfully achieved. Firstly, the GSA system demonstrated greater than 90 percent sulfur dioxide (SO_2) removal for a high-sulfur coal (i.e. greater than 4.5 lb SO_2/MBtu) application. Secondly, the emissions from the electrostatic precipitator (ESP) remained below the New Source Performance Standards for particulates (i.e. 0.03 lb/MBtu) during this run, leveling out at about 0.015 lb/MBtu. Thirdly, the GSA plant demonstrated the reliability and operability of this technology by achieving 91 percent SO_2 removal, during a 28-day period of continuous operation.

At the beginning of the operation/testing phase, a number of preliminary tests were conducted to determine the operating limits of the GSA demonstration system, and to define the relative importance of the various operating parameters. After the preliminary tests were completed in January 1993, a statistically-designed factorial test program was followed. The purpose of this factorial testing was to determine the effect of the process variables on the operation and SO_2 removal efficiency in the reactor/cyclone and the ESP/PJBH so as to optimize the GSA performance. The air toxic tests, which followed the factorial tests, were conducted to determine the capability of the GSA system in removing HCl, particulate and trace metals. The testing phase concluded with the 28-day continuous demonstration run of the GSA system.

This Environmental Monitoring Report (EMR) is a summary of the results of compliance and supplementary monitoring. Both compliance and supplementary monitoring are performed on gaseous, aqueous and solid streams. This report is based upon TVA's test reports during the testing and operation phase of the project. The following conclusions were drawn as a result of the compliance and supplementary monitoring.

- The GSA system averaged greater than 90 percent SO_2 removal efficiency over the course of this demonstration run, even when the boiler switched to a higher sulfur coal. This switch to the higher sulfur coal demonstrated that the GSA system is able to limit the SO_2 emission under the compliance level when the boiler is burned with higher-sulfur coal.

- The emission rate for the ESP remained well below the NSPS for particulate (0.03 lb/MBtu) throughout the run. The particulate emissions fluctuated from 0.007 lb/MBtu to 0.015 lb/MBtu about two weeks of operation. Then there was a steady state outlet at about 0.015 lb/MBtu, i.e., one-half the NSPS level.

- The 14-day Pulsed Jet Baghouse (PJBH) demonstration run showed that the GSA/PJBH system can achieve very high SO_2 and particulate removal efficiencies. These high SO_2 removal efficiencies (96+ percent) in the GSA/PJBH system were achieved at relatively modest Ca/S levels, i.e., 1.34 to 1.49 moles $Ca(OH)_2$/mole inlet SO_2, indicating that the Ca/S level required for achieving 91 percent SO_2 removal in a GSA/PJBH system would be substantially lower. The testing results also delineated that GSA/PJBH system showed higher removal efficiencies for both SO_2 and particulate than those achieved in GSA/ESP system.

- In accordance with the compliance monitoring results, the GSA demonstration system does not generate additional aqueous waste over the amount discharged from the plant during normal operations.

- The solid stream compliance monitoring shows that the solid waste or by-product streams are not discharged to the plant environment, and that the product can be safely disposed in a landfill.

- The installation of the GSA system at Shawnee Fossil Plant is capable of reducing the emission of gaseous pollutants to a level substantially below the compliance requirements.

- The GSA technology, used either at the Shawnee Fossil Plant, or other location, will bring about positive impact to the environment at the plants.

1.0 INTRODUCTION

In October, 1990, a Cooperative Agreement was signed by AirPol Inc. for the project entitled "10 MW Demonstration of Gas Suspension Absorption (GSA)". The purpose of this project is to demonstrate an innovative, energy-efficient clean coal technology especially for coal-fired flue gas treatment that is capable of being commercialized in the 1990s. As a part of the project summary reports, an approved Environmental Monitoring Plan (EMP) was prepared by Tennessee Valley Authority (TVA) and submitted to the United States (U.S.) Department of Energy (DOE) in October 1992. A revised EMP was submitted in June 1993 and subsequently approved by DOE. The EMP includes both compliance and supplemental monitoring of several gaseous, aqueous, and solid streams.

The demonstration project took place in three phases over a three-year period. The first phase began on August 1, 1990 and ended December 31, 1991. During this phase all engineering and design work was performed. It was during this phase that the detailed process flow diagrams, instrumentation diagrams, and design data sheets were prepared. Phase II began on January 1, 1992 and was completed on September 30, 1992. During Phase II, construction of the GSA system and procurement activities occurred. Construction and installation of the fabric filter were also completed during Phase II. Phase III, the operational and testing phase, began on October 1, 1992 and ended on February 28, 1994. Phase III consisted of the following four testing periods, involving approximately 100 to 120 individual tests: preliminary tests, factorial tests, air toxic tests, and the demonstration run.

The Environmental Monitoring Report (EMR) for the demonstration project is prepared based on the working scope listed in EMP. It presents the results of EMP activities conducted during GSA demonstration runs. Except for the PJBH, which was tested during a separate 14-day demonstration run, all the other data provided herein are based upon the period of 28-day demonstration run in phase III of the whole project. The operation of the GSA system during the 28-day demonstration run is representative of the operation of an average commercial GSA system. Figure 1.0 illustrates the locations of each of the monitoring activities relative to the GSA system structures. For the monitoring details other than the demonstration run period refer to the pertinent monitoring summary reports of this project. The air toxics testing results were presented in a separate report by Energy and Environmental Research Corporation (EER).

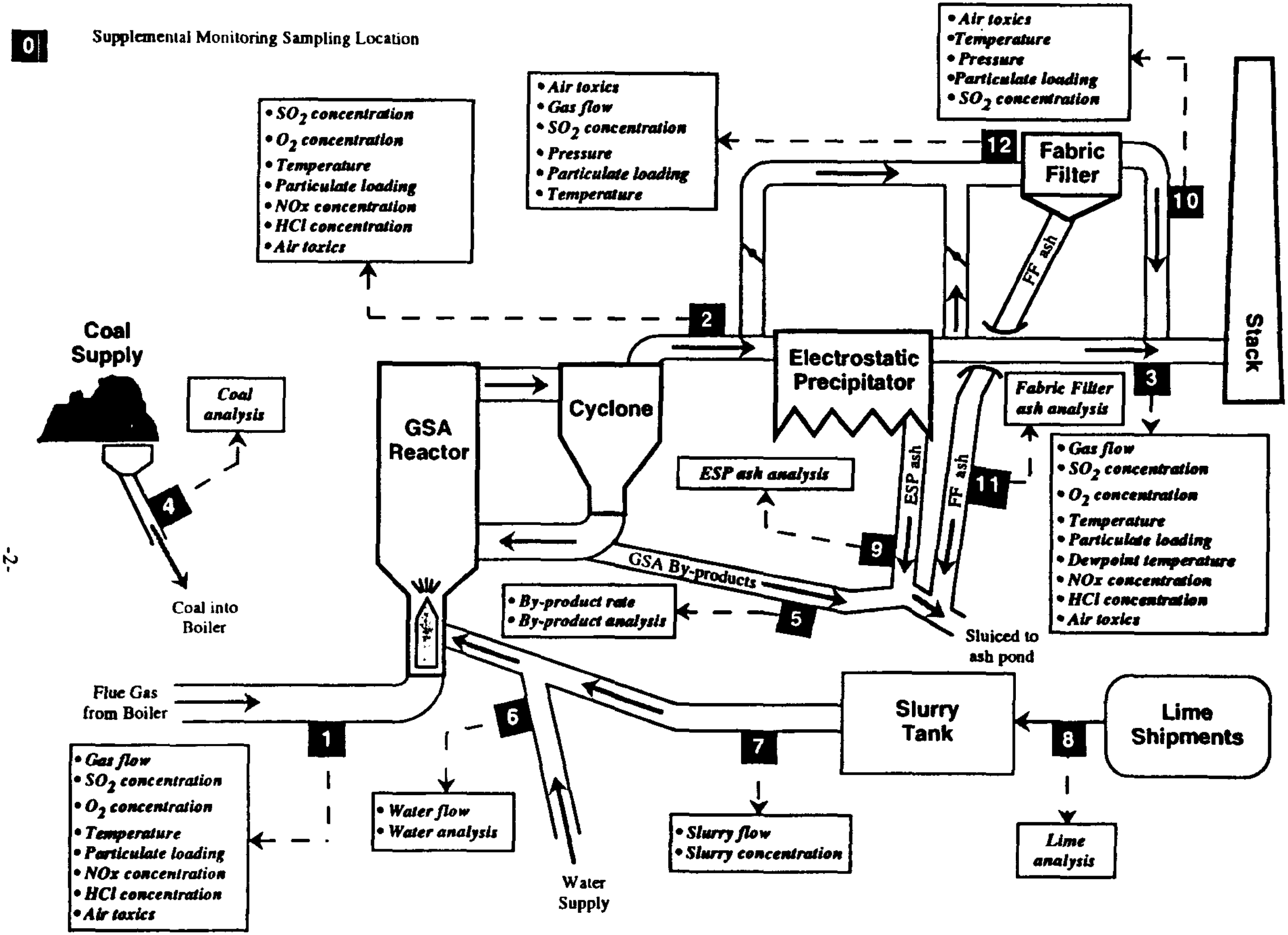

Figure 1.0 GSA System Environmental Monitoring

1.1 Process Description

The demonstration project involves the installation and testing of a 10-MW GSA system, a SO_2 emission control technology, on unit 9 boiler of TVA's Shawnee Fossil Plant. The GSA system is located at the Center for Emissions Research (CER), which is approximately 250 feet north of unit 9 boiler. For the demonstration project, about 7 % of the flue gas stream from unit 9 boiler is diverted to the CER and enters the bottom of the reactor. Slated lime slurry and cooling water are injected into the throat of the reactor by means of a dual fluid nozzle. The resulting atomized slurry coats the surface of the recirculating solids and fly ash particles. The acid gases in the flue gas and lime undergo a chemical reaction on the surface of the suspended solids. Meanwhile, the evaporation of the cooling and slurry water cools and humidifies the flue gas to the desired approach-to-saturation temperature. The major products of this reaction are calcium sulfite, calcium sulfate and calcium chloride. The partially cleaned flue gases leave the reactor and enter a cyclone where the solids containing the calcium salts, ash and unreacted lime are separated from the gas stream. About 99 % of the solids collected by the cyclone are recycled back to the reactor so that any unused lime can further react with acid gases in the flue gas. This lowers the overall lime consumption. The remaining 1 % of the solids from the cyclone leave the system at this point as by-product. The flue gases leave the separating cyclone and enter an existing electrostatic precipitator (ESP) for particulate collection. Cleaned flue gases are released to the atmosphere from the ESP through a separate pilot plant stack. The GSA system is designed to remove more than 90 % SO_2 using high sulfur U.S. coal. Coal sulfur content during the demonstration will range from 4 to 5 pounds of SO_2 per million Btu (lb SO_2/MBtu), about 2.7 % sulfur by weight. Higher sulfur coals may be used if supplies of the preferred coal were depleted.

Along with the operation and testing of the GSA, a 1-MW pulsed jet fabric filter (baghouse) was tested for a short period to evaluate its reliability and pollutant removal performance. The filter was connected to the ESP to allow testing of the filter and GSA system in four alternative arrangements: GSA with ESP and fabric filter in parallel, GSA with ESP and fabric filter in series, ESP and fabric filter in parallel without GSA, and ESP and fabric filter in series without GSA.

1.2 Project Location

The project was conducted at the TVA Shawnee Fossil Plant in McCracken County, Kentucky, located approximately 10 miles northwest of Paducah, Kentucky. The plant is located on the south bank of the Ohio River at river mile 945 on several hundred acres of river floodplain and a low upland terrace developed in thick deposits of unconsolidated clays, silts, and gravel. The active plant area is situated on this terrace, which lies above the 500-year floodplain. The Shawnee Fossil Plant currently operates 10 coal-fired boiler units with a total nameplate capacity of 1735 MW. Units 1-8 are fired with low-sulfur coal while units 9 and 10 are able to utilize a high-sulfur coal. Unit 9 currently supplies 7 % of its total flue gas to the GSA demonstration system. Units 1 through 9 are identical wall-fired Babcock and Wilcox boilers, each having a nameplate generating capacity of 175 MW, while unit 10 is a 160-MW Atmospheric Fluidized Bed Combustion boiler that was retrofitted in the 1980s.

1.3 Existing Operations

Unit 9 burned the same quantity and type of coal for the GSA demonstration project that was burned for the experimental FGD system. In the past, unit 9 has burned both a medium-to-high sulfur Pyro coal and a high-sulfur Warrior coal. The Pyro coal has an average sulfur content of 2.47 to 2.99 % by weight and a heating value of 12,000-13,000 Btu/lb. The Warrior coal has an average sulfur content of 3.5 to 4.1 % by weight and the same heating value as the Pyro coal. Unit 9 consumes coal at a rate of 60 tons/hr. The current air quality permit specifies that SO_2 emissions from unit 9 shall not exceed 8.0 lb SO_2/MBtu during those periods when unit 9 is being operated for the purpose of generating high SO_2 content flue gases for use in any experimental FGD system. For the year of 1989, with the experimental spray dryer in operation on unit 9, emissions from unit 9 were in the range of 4 to 5 lb SO_2/MBtu. If no experimental SO_2 removal system is being operated, then the emissions limit for SO_2 becomes 1.2 lb/MBtu and a low-sulfur coal must be burned in unit 9.

2.0 COMPLIANCE MONITORING RESULTS

Compliance monitoring is the monitoring required by agencies of the Federal, state, and local governments (other than DOE) to satisfy statutes, regulations, terms of leases, permits, and grants, and other requirements. This EMR addresses source monitoring as discussed below.

2.1 Gaseous Stream Monitoring

Air emissions from the Shawnee Fossil Plant are subject to the Clean Air Act, EPA regulations, and Kentucky Division for Air Quality (KDAQ) regulations. The KDAQ has issued a renewable permit to TVA for the boiler stacks with an emission limit of 1.2 lb SO_2/MBtu and 20 % opacity. The following sections cover both the SO_2 and Opacity at the GSA outlet stack so as to confirm the satisfaction of the regulations.

2.1.1 SO_2 Removal Efficiency

Table 2.1.1 presents the SO_2 removal efficiency during the demonstration run period classified by the test segments. The SO_2 concentration was measured by a Continuous Emission Monitoring (CEM) system located at the inlet and outlet of GSA, ESP and Fabric Filter, respectively. The average SO_2 concentrations at the outlet of ESP ranged from 105 ppm to 235 ppm without dramatically changing. Test segment 1-DR-01 to 1-DR-06 showed a steady state condition of SO_2 removal rate, within the range of 143 ~ 153 ppm for SO_2 outlet concentration. The average ESP outlet SO_2 content in the segment 1-DR-07 was a comparatively higher value of 235 ppm. This was a questionable result because a calibration problem was found after the completion of this test segment. The recalibration of the lime slurry flowmeter showed a satisfied 105 ppm SO_2 concentration at the outlet of the system for segment 1-DR-08. Each of these data is under the EPA and KDAQ specified discharge regulations for SO_2, i.e. 1.2 lb/MBtu.

Table 2.1.1

Average Inlet and Outlet SO_2 Concentration for Test Segments

Test Segment	Average GSA Inlet SO_2 Concentration, ppm	Average GSA Outlet SO_2 Concentration, ppm
1-DR-01	1,800	143
1-DR-02	1,800	148
1-DR-03	2,160	153
1-DR-04	2,100	148
3-DR-04	1,820	146
1-DR-05	1,750	146
1-DR-06	1,880	143
1-DR-07	1,840	235
1-DR-08	1,880	105

2.1.2 Opacity and Particulate Emissions

The opacity in the GSA system outlet stack is the another gaseous stream compliance parameter included in the EMP monitoring. This parameter is monitored continuously using a dedicated opacity meter. The opacity monitoring results were submitted by TVA. Average flue gas opacities at stack outlet and particulate emission rate on each of the test segment are given in Table 2.1.2-1. All of the opacity data during the demonstration run were below the KDAQ permit of 20% opacity. The opacity of the last five test segments, 3-DR-04 to 1-DR-08, are the results of using high-sulfur Andalex coal, while the others are under the condition of burning higher-sulfur coal, Warrior coal. The particulate emission control results for the factorial tests conducted at baseline chloride levels are presented in Table 2.1.2-2 for the 2-AP series tests and in Table 2.1.2-3 for the 3-AP series tests. Similarly, the particulate control results are presented in Tables 2.1.2-4 and 2.1.2-5 for the chloride spiking tests for the 2-AP and 3-AP series, respectively. In accordance with these test results, all the particulate emission rates are well below the compliance requirement, i.e. NSPS 0.03 lb/MBtu level.

Table 2.1.2-1

Average Outlet Opacity and Particulate for Test Segments

Test Segment	Average Particulate Emission Rate lb/MBtu	Average Opacity at Stack %
1-DR-01	0.0065	3.7
1-DR-02	0.0125	3.4
1-DR-03	0.0053	3.0
1-DR-04	0.0043	3.4
3-DR-04	0.0060	5.4
1-DR-05	0.0140	5.7
1-DR-06	0.0165	5.8
1-DR-07	0.0140	6.2
1-DR-08	--	5.5

Table 2.1.2-2

GSA Particulate Control Performance Results for 2-AP Series -- Baseline Tests

Test No.	Inlet Temp. °F	Gas Flow Rate scfm	ESP Eff. Conc. Basis (%)	ESP Emission lb/MBtu
2-AP-09	320	14,000	99.75	0.021
2-AP-79	320	14,000	99.98	0.001
2-AP-72	320	20,000	99.95	0.006
2-AP-16	320	20,000	99.97	0.004
2-AP-11	320	14,000	99.96	0.007
2-AP-81	320	14,000	99.96	0.004
2-AP-10	320	20,000	99.92	0.009
2-AP-80	320	20,000	99.98	0.001
2-AP-01	319	14,000	99.94	0.006
2-AP-71	320	14,000	99.91	0.008
2-AP-78	320	20,000	99.95	0.005
2-AP-04	320	19,000	99.90	0.009
2-AP-74	320	20,000	99.91	0.007
2-AP-03	319	14,000	99.88	0.014
2-AP-73	320	14,000	99.89	0.017
2-AP-95	320	20,000	99.94	0.005
2-AP-96	322	20,000	99.89	0.009
2-AP-14	320	18,000	99.94	0.010
2-AP-63	320	20,000	99.94	0.009
2-AP-63	320	20,000	99.92	0.013
2-AP-88	320	14,000	99.78	0.015
2-AP-87	320	20,000	99.94	0.006

Table 2.1.2-2 (Continued)

GSA Particulate Control Performance Results for 2-AP Series -- Baseline Tests

Test No.	Inlet Temp. °F	Gas Flow Rate scfm	ESP Eff. Conc. Basis (%)	ESP Emission lb/MBtu
2-AP-86	320	14,000	99.33	0.007
2-AP-97	320	20,000	99.97	0.029
2-AP-19	320	20,000	99.93	0.010
2-AP-57	319	19,500	99.93	0.010

Table 2.1.2-3

GSA Particulate Control Performance Results for 3-AP Series -- Baseline Tests

Test No.	Inlet Temp. °F	Gas Flow Rate scfm	ESP Eff. Conc Basis (%)	ESP Emission lb/MBtu
3-AP-12	320	14,000	99.70	0.030
3-AP-58	320	14,000	99.94	0.005
3-AP-42	320	14,000	99.89	0.012
3-AP-08	320	20,000	99.93	0.009
3-AP-44	319	14,000	99.59	0.008
3-AP-03	319	14,000	99.95	0.010
3-AP-26	260	14,000	99.87	0.016
3-AP-02	319	14,000	99.95	0.008
3-AP-18	319	14,000	99.94	0.007
3-AP-21	319	20,000	99.94	0.010
3-AP-20	320	14,000	99.90	0.014
3-AP-20	320	14,000	99.88	0.014
3-AP-13	319	14,000	99.92	0.009
3-AP-45	320	14,000	99.97	0.006
3-AP-19	320	20,000	99.91	0.009

Table 2.1.2-4

GSA Particulate Control Performance Results for 2-AP Series -- Chloride Spiking Tests

Test No.	Inlet Temp. °F	Gas Flow Rate scfm	ESP Eff. Conc. Basis (%)	ESP Emission lb/MBtu
2-AP-28	320	14,000	99.94	0.009
2-AP-75	320	14,000	99.94	0.010
2-AP-17	320	20,000	99.86	0.011
2-AP-82	320	20,000	99.94	0.004
2-AP-07	320	14,000	99.95	0.008
2-AP-77	320	14,000	99.95	0.005
2-AP-98	320	14,000	99.95	0.007
2-AP-06	320	20,000	99.90	0.012
2-AP-92	320	20,000	99.98	0.003
2-AP-91	320	20,000	99.96	0.006
2-AP-90	320	14,000	99.91	0.007
2-AP-25	320	18,000	99.91	0.014
2-AP-94	320	20,000	99.83	0.013
2-AP-85	320	20,000	99.92	0.008
2-AP-84	320	14,000	99.95	0.004
2-AP-24	320	14,000	99.90	0.011
2-AP-83	320	20,000	99.92	0.009

Table 2.1.2-5

GSA Particulate Control Performance Results for 3-AP Series -- Chloride Spiking Tests

Test No.	Inlet Temp. °F	Gas Flow Rate scfm	ESP Eff. Conc Basis (%)	ESP Emission lb/MBtu
3-AP-29	320	14,000	99.95	0.009
3-AP-22	320	14,000	99.96	0.004
3-AP-24	320	14,000	99.94	0.007
3-AP-23	320	19,200	99.95	0.008

2.2 Aqueous Stream Monitoring

Approximately 1.5 billion gallons of water are discharged to the Ohio River daily from the Shawnee Fossil Plant. Since the by-products from the GSA system are dry, no additional aqueous wastes are emitted over the amount discharged from the plant during normal operations.

2.3 Solid Stream Monitoring

The solid streams resulting from the operation of the GSA unit are expected to have the same composition as the spray-dryer wastes and by-products. In keeping with existing practices, these non-recyclable solids will be mixed with pilot plant ESP ash, diluted with water to generate a slurry containing approximately 10 % solids and pumped to an existing ash pond for dewatering and ultimate disposal with other ash. Changes in ash pond effluent quality or quantity as a result of the operation of the GSA are not expected. No permits are required for solid waste or by-product streams. No monitoring or measuring is performed of solid waste or by-product streams as specified in the EMP report.

3.0 SUPPLEMENTAL MONITORING RESULTS

Supplemental monitoring is required in addition to compliance monitoring to identify and characterize potential environmental and health impacts of the project, both on site and off site.

There are many variables affect the operation of the GSA system such as inlet gas volume, inlet SO_2 loading, inlet particulate loading, reinjection of waste into the GSA reactor, lime slurry concentration and feed rate, calcium chloride addition (at suction of slurry pump), and reactor outlet temperature etc. To characterize the effects of changes in these variables, several measurements of gaseous, aqueous, and solid streams were conducted. Specific monitoring results are described in the following sections.

3.1 Gaseous Stream Monitoring

3.1.1 Test Conditions

The test conditions of the demonstration run were selected based on the results from the previous factorial tests and the desire to achieve a minimum overall system (reactor/cyclone/ESP) SO_2 removal efficiency of 90 percent during the entire run. These selected test conditions are shown in Table 3.1.1-1.

Most of these test conditions represented operating parameter levels that would be required of a GSA on utility applications. The inlet flue gas temperature was set at 320 °F, which is a "normal" boiler air preheater outlet temperature for a unit burning a high-sulfur coal. The approach-to-saturation (ATS) temperature in the reactor/cyclone was set at 18 °F. This ATS temperature was dictated by another test parameter; the simulated coal chloride concentration of 0.12 weight percent. This chloride concentration is typical of many coals. The deliquescent nature of calcium chloride inhibits the evaporation of the water from the slurry that is injected into the reactor and an 18 °F ATS temperature was deemed to be necessary to ensure that all of the water in the feed slurry was evaporated. The 0.12 percent coal chloride level was simulated by spiking the lime slurry with a calcium chloride solution. The fly ash level was set at 2.0 gr/acf since this is a typical value for a pulverized-coal-fired boiler. The flue gas flow rate at the reactor inlet was set at the design value of 20,000 scfm. The recycle screw speed was set at 30 rpm, which is the lower of the two levels evaluated in the factorial test program. All of these values, except for the recycle screw speed, were fixed and were not changed during the 28-day demonstration run. The recycle screw speed was briefly increased to 45 rpm and then returned to 30 rpm. A chronology of the major events during the demonstration run are shown in Figure 3.1.1.

<u>Table 3.1.1-1</u>

**Test Conditions for the
28-Day Demonstration Run**

Variable	Level
Inlet flue gas temperature, °F	320
Approach-to-saturation temperature, °F	18
Fly ash loading, gr/acf	2
Coal chloride level, %	0.12
Flue gas flow rate, kscfm	20
Recycle screw speed, rpm	30
Overall system SO_2 removal, %	91

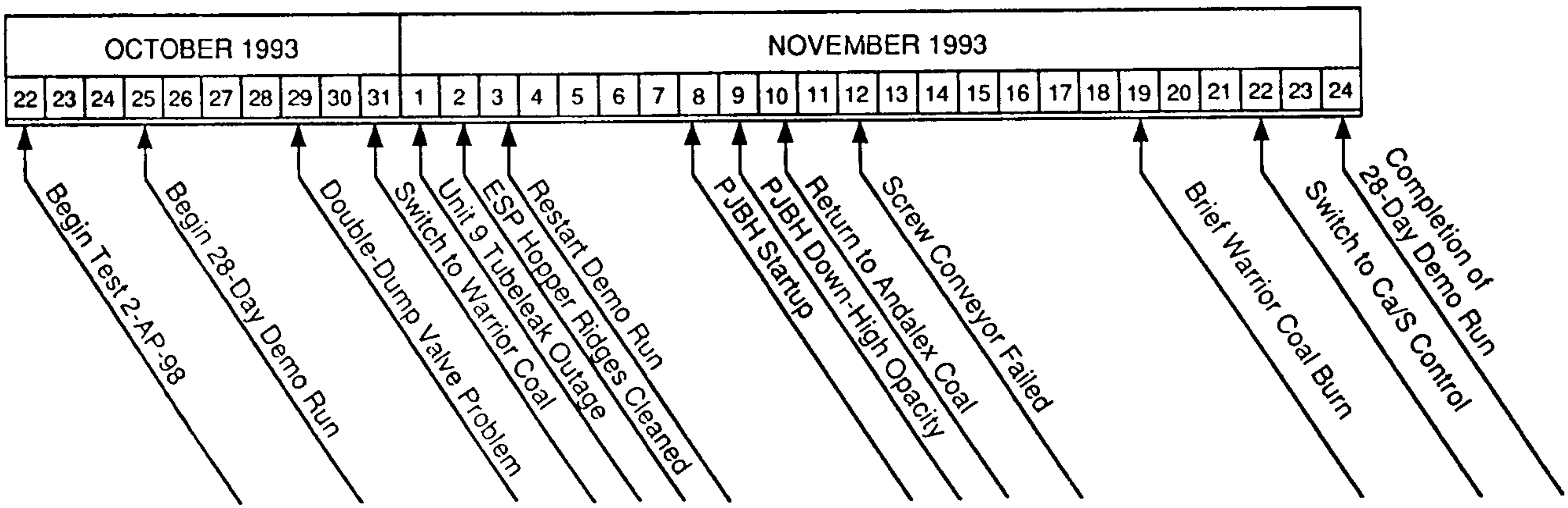

Figure 3.1.1 Timeline for the 28-Day Demonstration Run

The classification of the test segments are shown in Table 3.1.1-2. There were a total of 9 test segments during the 28-day demonstration run, with the specific dates for each test segment also shown in this table. One of the test segments included seven (7) days while some of the others included only two days or less. Table 3.1.1-2 also identifies the coal that was burned during each test segment. The last two test segments, 1-DR-07 and 1-DR-08, each of which represented a single day of testing during the last two days of the demonstration run, were different than the other segments in one important aspect. During these two segments, the operation of the GSA system was switch to the Ca/S control mode. The purpose of these two segments was to determine if the higher Ca/S level (1.43-1.50 moles $Ca(OH)_2$/mole inlet SO_2) needed earlier in the demonstration run was due to the use of the SO_2 control mode.

Table 3.1.1-2

Time Period and Coals for 28-Day Demonstration Run Test Segments

Test Segment	Time Period	Coal
1-DR-01	October 26-29	Andalex[a]
1-DR-02	October 29- November 1	Andalex/Warrior[b]
1-DR-03	November 3-7	Warrior
1-DR-04	November 7-8	Warrior
3-DR-04	November 8-12	Warrior/Andalex
1-DR-05	November 12-19	Andalex
1-DR-06	November 19-22	Andalex
1-DR-07	November 22-23	Andalex
1-DR-08	November 23-24	Andalex

a: 2.7 percent sulfur coal.
b: 3.5 percent sulfur coal.

3.1.2 SO_2 Removal Efficiency

The average overall system SO_2 removal efficiency data are shown by test segment in Table 3.1.2. The overall system SO_2 removal efficiency ranged from 89.9 to 91.6 percent for the 7 test segments completed in the SO_2 removal control mode. The overall system SO_2 removal efficiencies in the other two test segments were 84.4 percent in segment 1-DR-07 and 93.4 percent in segment 1-DR-08. These two short test segments were run in the Ca/S control mode.

The average Ca/S level in each test segment is also noted in Table 3.1.2. The Ca/S levels range from 1.32 to 1.58 moles $Ca(OH)_2$/mole inlet SO_2. During segment 1-DR-01, the SO_2 control mode was used and the overall system SO_2 removal efficiency of 90.8 percent was achieved at a Ca/S level of 1.45 moles $Ca(OH)_2$/mole inlet SO_2. In segment 1-DR-08 where the Ca/S control mode was used, the overall system SO_2 removal efficiency was 93.4 percent at the same Ca/S level.

The test results showed that AirPol's GSA is capable of substantially reducing the SO_2 emission from a coal fired boiler, and installation of the GSA system will bring about positive impact on the SO_2 emission at the plant location.

Table 3.1.2

Average Inlet SO_2 Concentration, Ca/S Level, and Overall System SO_2 Removal Efficiency During Demonstration Run Test Segments

Test Segment	Average Inlet SO_2 Concentration, ppm	Average Ca/S Level	Overall System SO_2 Removal Efficiency, %
1-DR-01	1,800	1.45	90.8
1-DR-02	1,800	1.47	90.3
1-DR-03	2,160	1.58	91.6
1-DR-04	2,100	1.46	91.4
3-DR-04	1,820	1.32	90.5
1-DR-05	1,750	1.52	90.2
1-DR-06	1,880	1.43	89.9
1-DR-07	1,840	1.40	84.4
1-DR-08	1,880	1.45	93.4

3.1.3 Particulate Removal Efficiency---ESP Performance

Average Emission Rates

The ESP outlet emission rate data are given in Figure 3.1.3-1 as a function of the test segment. The average values for each test segment are the dark circles while the results from the individual mass loading runs are indicated by the open circles. The average emission rate is initially very low at about 0.0075 lb/MBtu and remains relatively constant at this level through both of the first two test segments, 1-DR-01 and 1-DR-02. However, the data from the individual mass loading runs show a somewhat wider range, from 0.004 to 0.011 lb/MBtu in segment 1-DR-01 and from 0.004 to 0.0125 lb/MBtu in segment 1-DR-02.

The average emission rate for test segment 1-DR-03 was somewhat lower at 0.005 lb/MBtu, although the individual results ranged from 0.003 to 0.011 lb/MBtu. This better ESP performance, i.e., lower emission rate, continued through the next test segment, 1-DR-04. The individual emission rates during 1-DR-04 ranged widely, however, from 0.0025 to about 0.011 lb/MBtu.

Test segment 3-DR-04, which began on November 7, was the last of the test segments with a low emission rate, averaging about 0.006 lb/MBtu. The boiler switched back to the Andalex coal early in this test segment, although this is not thought to have had any effect on the ESP performance. The average emission rate increased to nearly 0.015 lb/MBtu in the following test segment, 1-DR-05, but the range of individual values was much wider than in the previous test segments (0.007 to about 0.024 lb/MBtu).

The next test segment, 1-DR-06, was similar to the previous test segment in that the average emission rate for this segment was relatively high at 0.016 lb/MBtu and the individual emission rates ranged from about 0.008 to 0.024 lb/MBtu. The average emission rate for test segment, 1-DR-07, dropped slightly to about 0.014 lb/MBtu, which is comparable to the level seen in test segment 1-DR-05 and only slightly lower than that in segment 1-DR-06. The three individual emission rates during segment 1-DR-07 showed a very narrow range from 0.011 to 0.018 lb/MBtu.

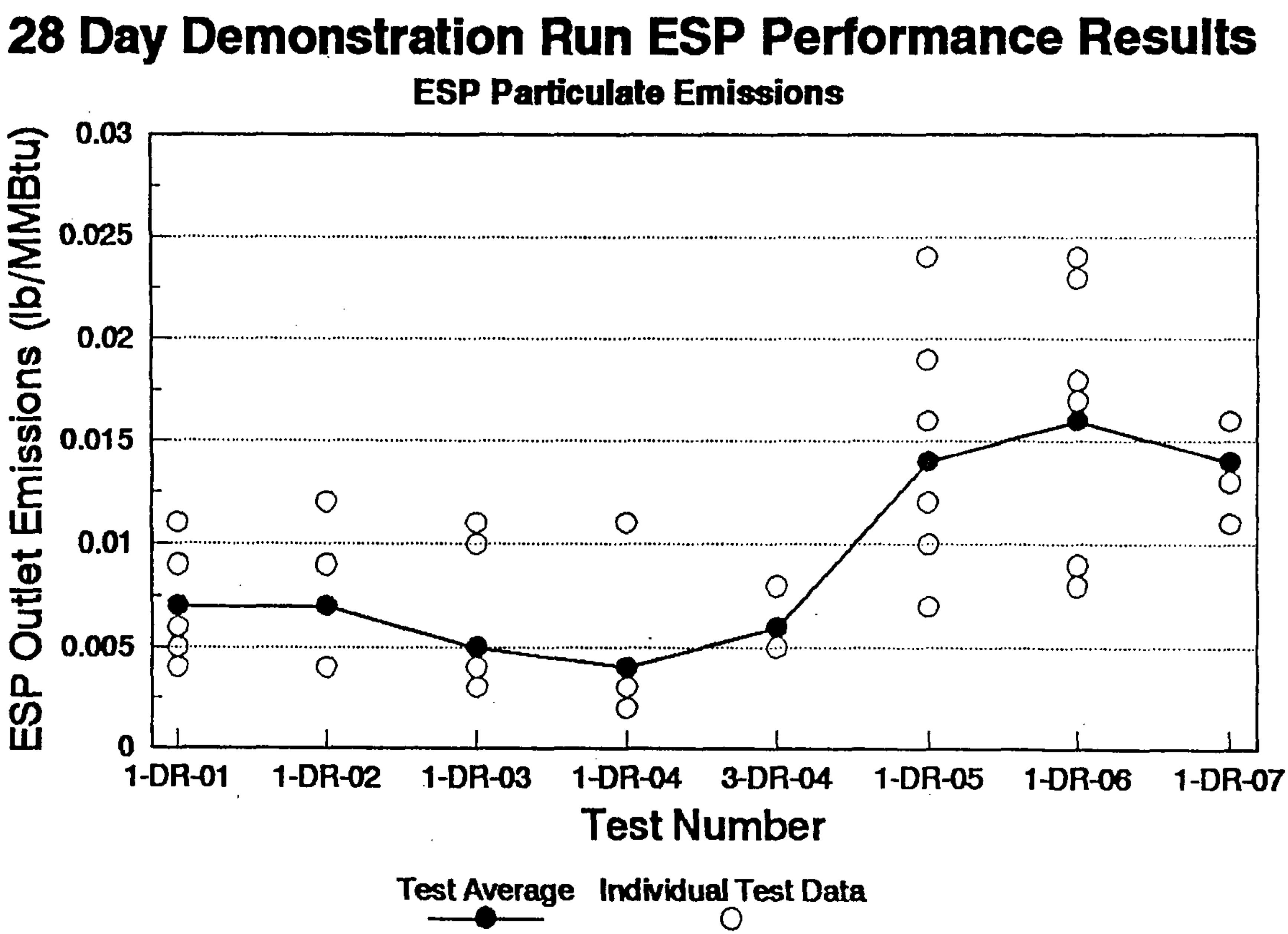

Figure 3.1.3-1 28-Day Demonstration Run --- ESP Performance Results

Daily Average Emission Rates

Since the individual mass loading results for each segment showed a wide variation around the average emission rate and the length of each test segment varied, a timeline was used to show the daily average emission rates during the course of the 28-day demonstration run. The emission rate data from each mass loading run are shown in Table 3.1.3 and the resulting daily average values are shown graphically in the timeline in Figure 3.1.3-2. The emission rates from the ESP start at a very low level, in the range of 0.005 to 0.009 lb/MBtu, during the first two weeks of the demonstration run. The substantially higher emission rate on October 30, 1993 seems out of place and is being treated as an outlier since this sampling may have been adversely affected by the double-dump valve problem on the previous day. Based upon the test results, it is concluded that installation of the GSA unit bring about positive impact to the environmental at the plant location.

Table 3.1.3

ESP Data by Test Segment During 28-Day Demonstration Run

Test Segment	Date	Grain Loading Inlet gr/acf	Grain Loading Outlet gr/acf	Particulate Removal Efficiency %	Emission Rate lb/MBtu
1-DR-01	10/26	4.362 4.826	0.0016 0.0015	99.96 99.97	0.006 0.005
	10/27	4.722 4.534 4.789	0.0033 0.0020 0.0028	99.93 99.95 99.94	0.011 0.006 0.009
	10/28	4.464 4.641 4.528	0.0027 0.0020 0.0023	99.96 99.97 99.97	0.006 0.004 0.005
1-DR-02	10/30	4.623 3.826 3.977	0.0043 0.0055 0.0077	99.91 99.86 99.81	0.016 0.021 0.027
	10/31	4.424 4.191 4.314	0.0035 0.0010 0.0028	99.92 99.98 99.94	0.012 0.004 0.009
	11/01	4.703 4.521	0.0021 0.0010	99.96 99.98	0.007 0.004
1-DR-03	11/04	4.565 4.836 4.966	0.0009 0.0011 0.0033	99.98 99.98 99.93	0.003 0.004 0.011
	11/05	4.596 4.810 4.644	0.0012 0.0030[a] 0.0013	99.97 99.94 99.97	0.004 0.010 0.004
	11/06	4.369 4.492 4.342	0.0014 0.0012 0.0010	99.97 99.97 99.98	0.005 0.004 0.003

Table 3.1.3 (Continued)

ESP Data by Test Segment During Demonstration Run

Test Segment	Date	Grain Loading Inlet gr/acf	Grain Loading Outlet gr/acf	Particulate Removal Efficiency %	Emission Rate lb/MBtu
1-DR-04	11/07	4.255 4.472 4.214	0.0010 0.0008 0.0011	99.98 99.98 99.98	0.003 0.003 0.004
	11/08	4.007 4.497 4.253	0.0010 0.0008 0.0033	99.98 99.98 99.92	0.003 0.002 0.011
3-DR-04	11/09	4.246 4.234 4.206	0.0015 0.0015 0.0024	99.97 99.97 99.95	0.005 0.005 0.008
1-DR-05	11/13	5.030 4.821	0.0050 0.0059	99.90 99.88	0.016 0.019
	11/14	4.906 4.869 4.774	0.0031 0.0034 0.0073	99.94 99.93 99.85	0.012 0.012 0.024
	11/18	4.765 4.918 4.780	0.0028[b] 0.0039 0.0023	99.95 99.92 99.95	0.010 0.012 0.007
1-DR-06	11/20	4.404 5.020 4.804	0.0050 0.0056 0.0072	99.89 99.86 99.85	0.017 0.018 0.024
	11/21	3.971 4.025 4.099	0.0027 0.0025 0.0069	99.93 99.94 99.83	0.009 0.008 0.023
1-DR-07	11/23	3.851 4.047 4.057	0.0046 0.0040 0.0033	99.87 99.90 99.92	0.018 0.013 0.011

a: Metal flakes noted in ESP outlet filter.
b: Problems with plugged filter and lines.

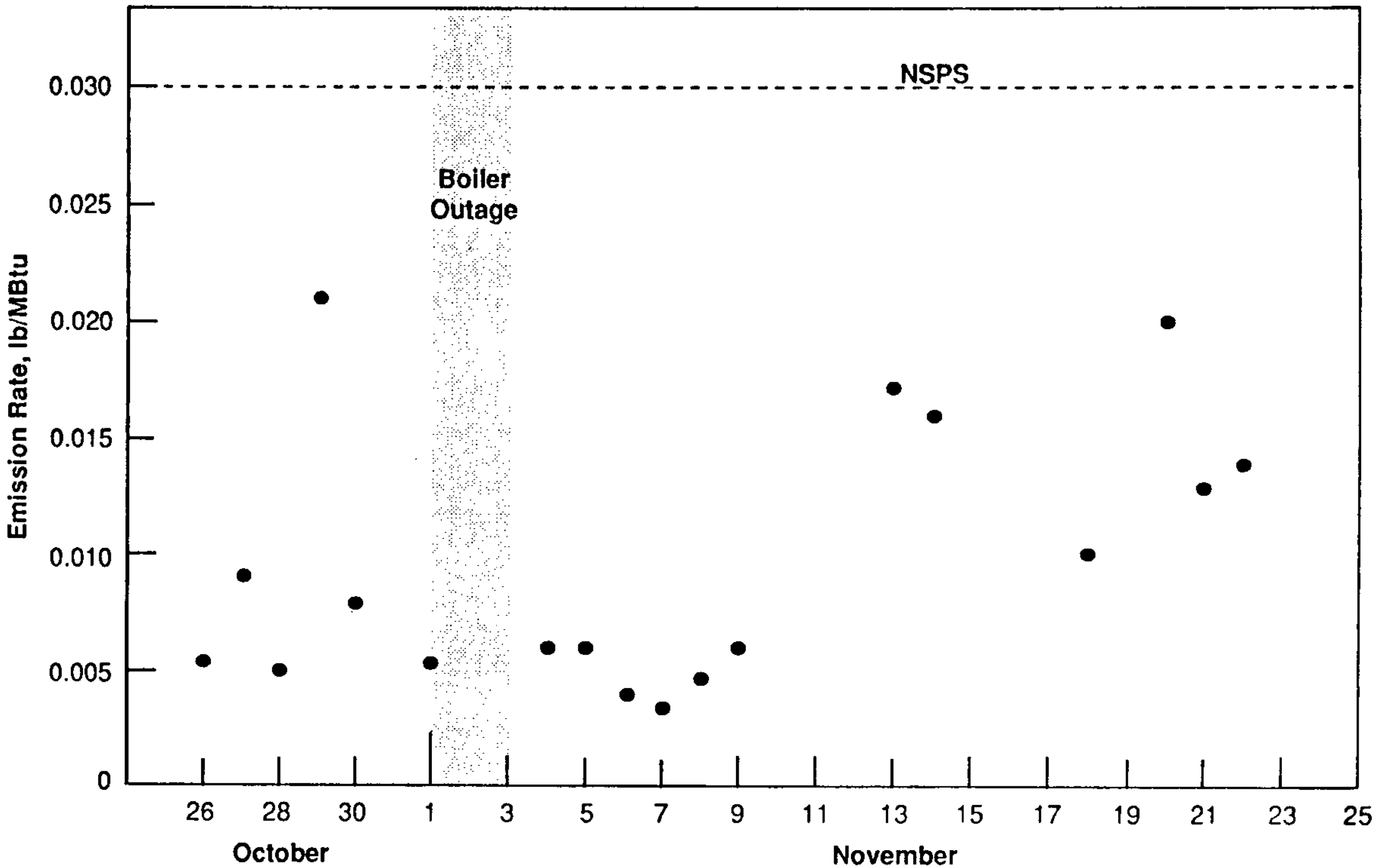

Figure 3.1.3-2 Daily Average ESP Emission Rate

3.1.4 PJBH Performance

The 1-MW PJBH pilot plant was operated in the "in-parallel" mode relative to the ESP, i.e., pulling flue gas from the ESP inlet, during this run.

The test conditions for the 14-day PJBH demonstration run were essentially the same as those used in the previous 28-day GSA demonstration run. The 14-day demonstration run was begun with test segment 1-PJ-01. Table 3.1.4-1 shows the four test segments, the time periods during which they were run, and the coal that was burned during each test segment. One of the test segments, 1-PJ-03, was interrupted when a problem with the stacker/reclaimed in the coal yard made it necessary to load low-sulfur, compliance coal in Unit 9 boiler. Since the GSA/PJBH system had not caused this operability problem, the PJBH demonstration run was resumed at the point that it had been interrupted after Unit 9 boiler was switched back to burning the high-sulfur Andalex coal on March 9. The demonstration run was completed at 1700 hours on March 16, 1994.

Table 3.1.4-1

Time Period and Coals for 14-Day PJBH Demonstration Run Test Segments

Test Segment	Time Period	Coal
1-PJ-01	February 25-28	Andalex[a]
1-PJ-02	March 1-3	Andalex
1-PJ-03	March 4-6	Andalex
-----	March 7-8	Low-sulfur compliance coal
1-PJ-03	March 9-10	Andalex
1-PJ-04	March 11-16	Andalex

a: 2.7 percent sulfur coal.

SO_2 Removal Efficiency

The average overall system SO_2 removal efficiency results are listed for both the GSA/ESP and the GSA/PJBH systems by test segment in Table 3.1.4-2, and shown graphically in Figure 3.1.4-1. Also shown in this table are the average inlet SO_2 concentration and the average Ca/S level for each test segment in the PJBH demonstration run. The inlet SO_2 concentration data ranged very narrowly, from only about 1,760 to 1,850 ppm, and reflected the fact that the GSA system was shut down during the period when the boiler was burning the low-sulfur compliance coal. The SO_2 removal efficiencies for the GSA/PJBH system were relatively consistent and were substantially higher than those achieved by the GSA/ESP system, ranging from 96.1 to 99.0 percent. The higher SO_2 removals in the GSA/PJBH system were not unexpected given the intimate contact between the SO_2 in the flue gas and the alkaline material collected on the bags in the PJBH. However, the magnitude of the difference at about 5 to 8 percentage points higher than that achieved in the reactor/cyclone/ESP system was somewhat surprising. Based on the results from the previous factorial testing, the difference in SO_2 removal efficiencies between the two systems was expected to be only about 2 to 5 percentage points.

Table 3.1.4-2

Average Inlet SO_2 Concentration, Ca/S Level, and Overall System

SO_2 Removal Efficiency During PJBH Demonstration Run Test Segments

Test Segment	Average Inlet SO_2 Concentration, ppm	Average Ca/S Level	Overall System SO_2 Removal Efficiency, % GSA/ESP	Overall System SO_2 Removal Efficiency, % GSA/PJBH
1-PJ-01	1,853	1.37	91.4	98.3
1-PJ-02	1,759	1.41	90.0	96.1
1-PJ-03	1,824	1.34	91.3	96.9
1-PJ-04	1,802	1.49	91.2	99.0

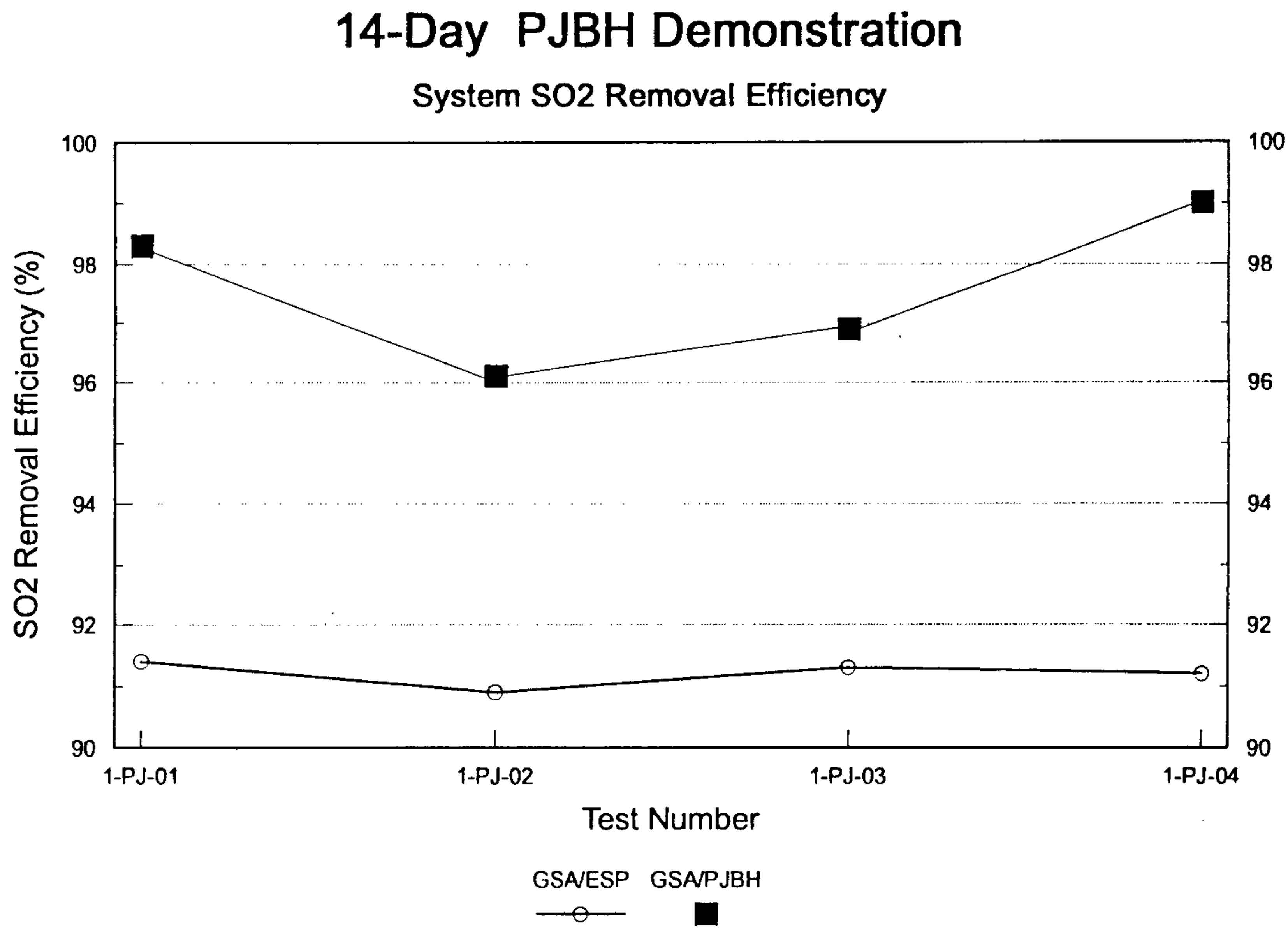

Figure 3.1.4-1 SO_2 Removal Efficiency for 14-Day PJBH Demonstration Run

Particulate Removal Efficiency

The PJBH which was treating a slipstream of flue gas from the ESP inlet containing the full dust loading, achieved very good performance. The results from the individual PJBH mass loading runs for each test segment during the 14-day run are shown in Table 3.1.4-3. A total of 11 mass loading runs were completed around the PJBH. There were usually only two mass loading runs completed each day because of the very low PJBH outlet grain loading. The technique required that the PJBH outlet sampling continue until a certain weight of sample has been obtained. With the very low PJBH outlet grain loadings (0.0002-0.0009 gr/acf), the outlet sampling time for each mass loading run was typically 3-5 hours.

The inlet grain loadings to the PJBH ranged from 2.81 to 3.72 gr/acf, while the outlet grain loadings were uniformly very good, ranging from 0.0002 to 0.0009 gr/acf. These inlet and outlet grain loadings yield particulate removal efficiencies of 99.97 to 99.99 percent, with more than three quarters of the individual values at the 99.99 percent level. The outlet grain loadings correspond to emission rates which are an order of magnitude below the New Source Performance Standards (NSPS).

The PJBH particulate removal efficiency and outlet emission rate data for the demonstration run are shown in Figure 3.1.4-2 and 3.1.4-3, respectively, as a function of the test segment. The average values for each test segment are shown as dark circles in this figure, while the results from the individual mass loading runs are indicated by the open circles. For most of the test segments, no individual run values are apparent in this figure because these values were identical to the average for the test segment.

Table 3.1.4-3

PJBH Data By Test Segment

During The 14-Day PJBH Demonstration Run

Test Segment	Date	Grain Loading Inlet gr/acf	Grain Loading Outlet gr/acf	Particulate Removal Efficiency %	Emission Rate lb/MBtu
1-PJ-01	2/26	3.065 3.214	0.0004 0.0004	99.99 99.99	0.001 0.001
	2/28	2.944 2.814	0.0002 0.0002	99.99 99.99	0.001 0.001
1-PJ-02	3/02	3.459 3.715	0.0009 0.0009	99.97 99.97	0.003 0.003
	3/04	2.854 3.447	0.0004 0.0004	99.99 99.99	0.001 0.001
1-PJ-03	3/06	3.383	0.0008	99.98	0.002
1-DR-04	3/12	3.328 3.556	0.0003 0.0003	99.99 99.99	0.001 0.001

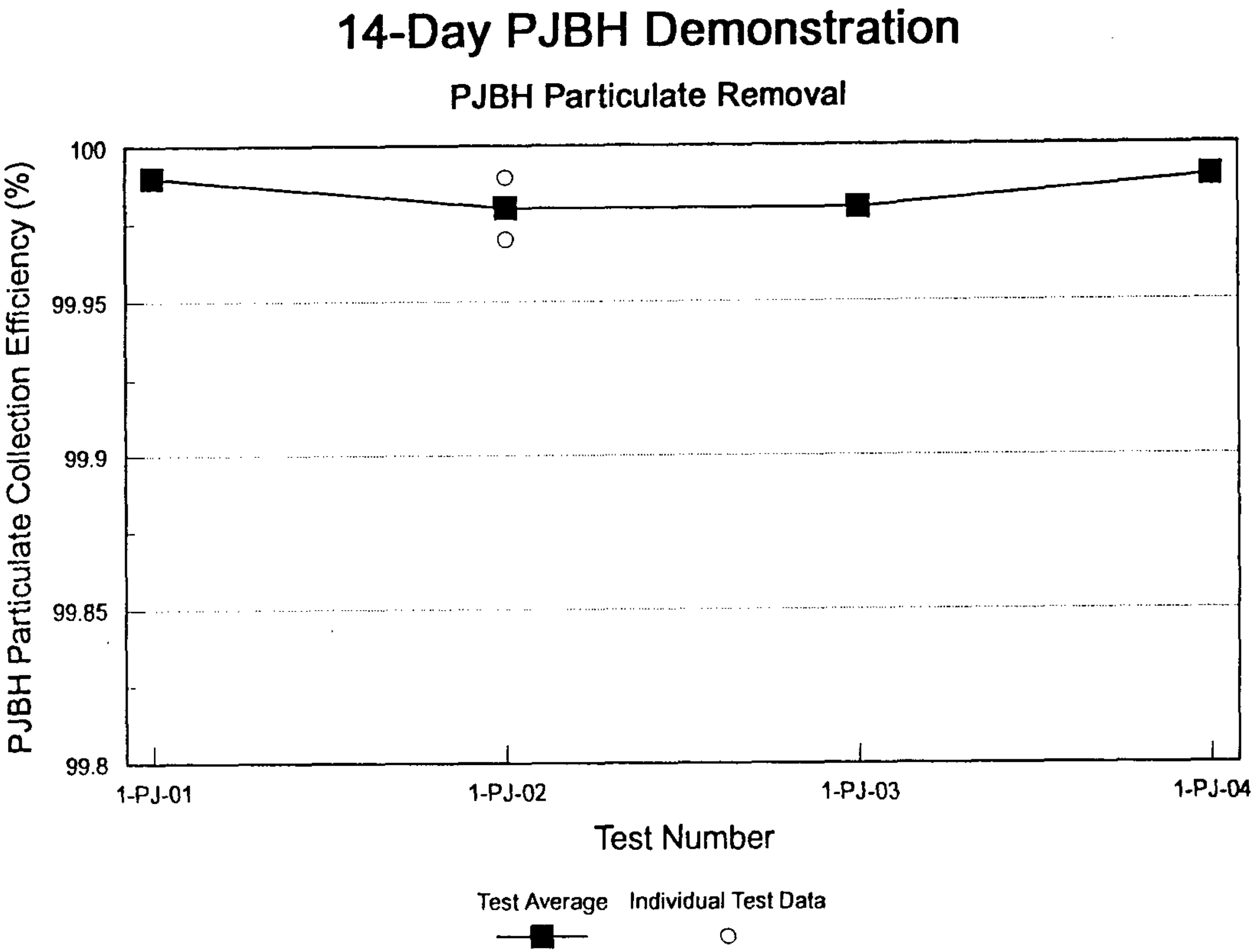

Figure 3.1.4-2 Particulate Removal for 14-Day PJBH Demonstration Run

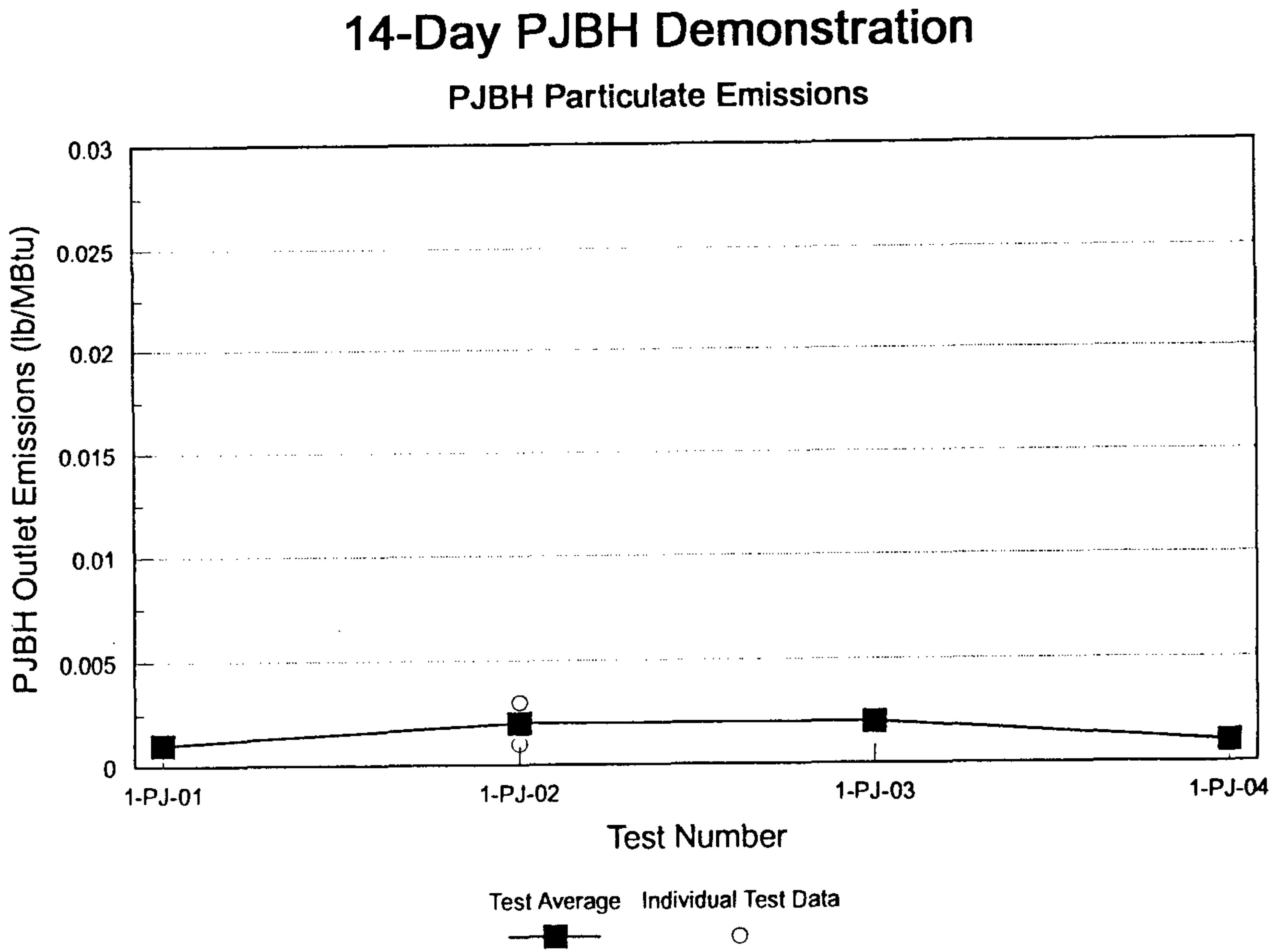

Figure 3.1.4-3 Particulate Emissions for 14-Day PJBH Demonstration Run

Discussion of GSA/PJBH and GSA/ESP Particulate Results

The PJBH operating downstream of the GSA system in the "in-parallel" mode demonstrated a very high particulate removal efficiency, which was much higher than that achieved in the ESP. The particulate removal efficiency in the PJBH was also much more consistent than that in the ESP, ranging from only 99.97 percent to 99.99 percent, as shown in the comparison in Figure 3.1.4-4. The particulate removal efficiency in the ESP was initially relatively high at 99.95 percent, but gradually dropped to 99.90 percent or less.

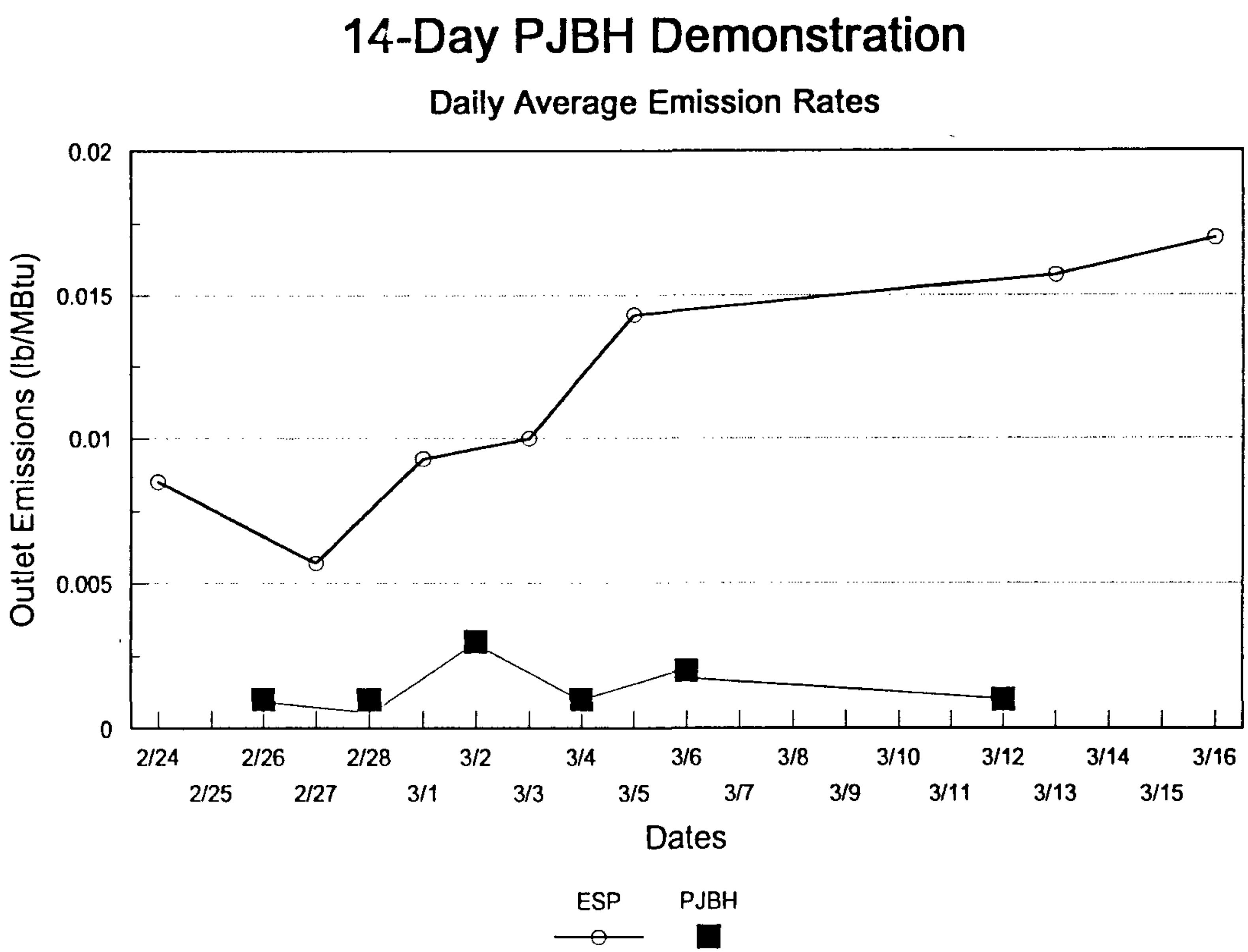

Figure 3.1.4-4 Particulate Daily Average Emission Rates for 14-Day PJBH Demonstration Run

3.2 Aqueous Stream Monitoring

Since the by-products from the GSA system are dry, no additional aqueous wastes are emitted over the amount discharged from the plant during normal operations.

3.3 Solid Stream Monitoring

By products from the GSA and ESP are the solid streams sampled as part of the EMP. This section summarizes the results of the by product analyses performed during the demonstration run. The analytical data listed in Table 3.3 were the average results of test segment 1-DR-01, which are considered as the representative of a high-sulfur coal applications. It can be noted from the table that the available alkalinity as $Ca(OH)_2$ is only 4.8 percent by weight from reactor system, located at the feeder box overflow, which is less than 11.1 percent and 6.7 percent by weight from ESP field number one (1) hopper and field number two (2) to four (4) hoppers, respectively. The reason is that reagent lime was recycled about 100 times before discharging from the GSA system. This is a salient advantage for GSA system with high utilization efficiency of the reagent through recycling means and lower concentration of unreacted lime in the by product and thus a minimum of by product residue. Table 3.3 also indicates that the amount of sulfite (SO_3) is larger than that of the sulfate (SO_4) and without any sodium (Na) in the solid streams.

Table 3.3

Solid Stream Analytical Data

Item, (wt %)	Reactor Product	ESP Field #1	ESP Field #2-4
Ca	16.5	22.0	25.0
Mg	0.1	0.11	0.14
Na	0.0	0.0	0.0
CO_3	5.8	5.8	7.95
Avail. Alk. as $Ca(OH)_2$	4.8	11.1	6.7
Cl	0.27	0.53	0.71
SO_3	18.6	23.7	30.7
SO_4	0.94	0.71	1.14
Total Sulfur	22.7	28.6	37.8
Acid Insolubles	50.0	33.9	21.55
Moisture	0.34	0.71	0.80
Ionic Imbalance, (%)	3.73	0.29	0.04
Total	96.9	94.7	94.4
Bulk Density, (lb/ft^3)	58.35	27.56	20.20

4.0 CONCLUSIONS

The following conclusions were drawn as a result of the data presented in this demonstration run:

- The GSA system averaged greater than 90 percent SO_2 removal efficiency over the course of this demonstration run, even when the boiler switched to a higher sulfur coal. This switch to the higher sulfur coal demonstrated the flexibility of the GSA system.

- The emission rate for the ESP remained well below the NSPS for particulate (0.03 lb/MBtu) throughout the run. The particulate emissions fluctuated from 0.007 lb/MBtu to 0.015 lb/MBtu about two weeks of operation. Then there was a steady state outlet at about 0.015 lb/MBtu, i.e., one-half the NSPS level.

- The 14-day Pulsed Jet Baghouse (PJBH) demonstration run showed that the GSA/PJBH system can achieve very high SO_2 and particulate removal efficiencies. These high SO_2 removal efficiencies (96+ percent) in the GSA/PJBH system were achieved at relatively modest Ca/S levels, i.e., 1.34 to 1.49 moles $Ca(OH)_2$/mole inlet SO_2, indicating that the Ca/S level required for achieving 91 percent SO_2 removal in a GSA/PJBH system would be substantially lower. The testing results also delineated that GSA/PJBH system showed higher removal efficiencies for both SO_2 and particulate than those achieved in GSA/ESP system.

- In accordance with the compliance monitoring results, the GSA demonstration system does not generate additional aqueous waste over the amount discharged from the plant during normal operations.

- The solid stream compliance monitoring shows that the solid waste or by-product streams are not discharged to the plant environment, and that the product can be safely disposed in a landfill.

- The installation of GSA system at Shawnee Fossil Plant is capable of reducing the emission of gaseous pollutants to a level substantially below the compliance requirements.

- The GSA technology, used either at the Shawnee Fossil Plant, or other location, will bring about positive impact to the environment at the plants.

5.0 REFERENCES

1. Environmental Monitoring Plan Gas Suspension Absorption Demonstration Project Shawnee Test Facility, Tennessee Valley Authority, October 1992.

2. Summary Report: 28-Day Demonstration Run, Tennessee Valley Authority, December 1993.

3. Summary Report: 14-Day Pulsed Jet Baghouse (PJBH) Demonstration Run, Tennessee Valley Authority, May 1994.